

What is claimed is:

1. An N-symbol noncoherent demodulator for a differential phase shift keyed (DPSK) type telecommunications signals, comprising:

a) means for storing indications of quadrature components $X(q)$ and $Y(q)$ of N consecutive received symbols of the telecommunications signals, where q is a symbol index, and N is an integer equal to at least three;

b) processing means for processing said indications according to

$$VX_{i+1}(k_1, k_2, \dots, k_i) = VX_i(k_1, k_2, \dots, k_{i-1}) + UX_{i+1}(k_1, k_2, \dots, k_i),$$

$$VY_{i+1}(k_1, k_2, \dots, k_i) = VY_i(k_1, k_2, \dots, k_{i-1}) + UY_{i+1}(k_1, k_2, \dots, k_i),$$

where i is an iteration index with $i=1,2,\dots,N-1$, k_i is an index of a phase differences between symbols with $k_i = 1,2,\dots,M$, with M being the number of permissible phase transitions, and where $VX_{i+1}(k_1, k_2, \dots, k_i)$ and $VY_{i+1}(k_1, k_2, \dots, k_i)$ are quadrature components at the i -th iteration, such that $VX_1=X(q-N+1)$, $VY_1=Y(q-N+1)$ are quadrature components of the first received symbol in the sequence of said N symbols, and $UX_{i+1}(k_1, k_2, \dots, k_i)$ and $UY_{i+1}(k_1, k_2, \dots, k_i)$ are transforms of the received symbol at the i -th step according to

$$UX_{i+1}(k_1, k_2, \dots, k_i) = X(q-N+i+1)\cos[\Delta(k_1)+\dots+\Delta(k_i)] + Y(q-N+i+1)\sin[\Delta(k_1)+\dots+\Delta(k_i)]$$

$$UY_{i+1}(k_1, k_2, \dots, k_i) = Y(q-N+i+1)\cos[\Delta(k_1)+\dots+\Delta(k_i)] - X(q-N+i+1)\sin[\Delta(k_1)+\dots+\Delta(k_i)];$$

and

c) decision means for determining a current symbol based on a phase difference $\Delta(k_i)$ corresponding to a maximum length of vectors defined by a relationship utilizing $VX_{i+1}(k_1, k_2, \dots, k_i)$ and $VY_{i+1}(k_1, k_2, \dots, k_i)$.

2. A demodulator according to claim 1, wherein:

said relationship is $[VX_{i+1}(k_1, k_2, \dots, k_i)]^2 + [VY_{i+1}(k_1, k_2, \dots, k_i)]^2$.

3. A demodulator according to claim 1, wherein:

said means for storing indications comprises delay elements.

4. A demodulator according to claim 1, wherein:

said delay elements comprise memory.

5. A demodulator according to claim 1, wherein:

said memory comprises shift registers.

6. A demodulator according to claim 1, wherein:

said processing means comprises a plurality of intersymbol processors, a first of said plurality of intersymbol processors generating two-symbol quadrature components VX_2 and VY_2 utilizing said quadrature components $X(q)$ and $Y(q)$ of a first two of said N consecutive received symbols, and a second of said intersymbol processors generating three-symbol quadrature components VX_3 and VY_3 utilizing said two-symbol quadrature components and a third of said N consecutive received symbols.

7. A demodulator according to claim 6, wherein:

said plurality of intersymbol processors comprise $N-1$ intersymbol processors.

8. A demodulator according to claim 7, wherein $N=3$.

9. A demodulator according to claim 1, wherein:

said differential phase shift keyed (DPSK) type telecommunications signals are differential quadrature phase shift keyed (DQPSK) telecommunications signals, and said phase differences $\Delta(k_i)$ are selected from a set of phase differences $0, \pi/2, \pi$, and $3\pi/2$.

10. A demodulator according to claim 9, wherein:

said processing means comprises table lookup means and tables.

11. A demodulator according to claim 9, wherein:

$N=4$.

12. A telecommunications receiver incorporating said N-symbol noncoherent demodulator of claim 1, and further comprising:

a channel interface adapted to receive said DPSK type telecommunications signals;
an in phase/quadrature (I/Q) detector coupled to said channel interface and to said noncoherent demodulator; and
a decoder coupled to said decision means.

13. A telecommunications receiver according to claim 12, wherein:

said DPSK type telecommunications signals are received by said channel interface on a single carrier, and said I/Q detector provides said indications of quadrature components $X(q)$ and $Y(q)$ to said noncoherent demodulator.

14. A telecommunications receiver according to claim 12, further comprising:

Fourier transform means coupling said I/Q detector and said noncoherent demodulator, wherein

said DPSK type telecommunications signals are received by said channel interface on multiple carriers, and said Fourier transform means provides said noncoherent demodulator with indications of quadrature components $X(q)$ and $Y(q)$ for each carrier.

15. A telecommunications receiver according to claim 12, wherein:

said relationship is $[VX_{i+1}(k_1, k_2, \dots, k_i)]^2 + [VY_{i+1}(k_1, k_2, \dots, k_i)]^2$.

16. A telecommunications receiver according to claim 12, wherein:

said processing means comprises a plurality of intersymbol processors, a first of said plurality of intersymbol processors generating two-symbol quadrature components VX_2 and VY_2 utilizing said quadrature components $X(q)$ and $Y(q)$ of a first two of said N consecutive received symbols, and a second of said intersymbol processors generating three-symbol quadrature components VX_3 and VY_3 utilizing said two-symbol quadrature components and a third of said N consecutive received symbols.

17. A telecommunications receiver according to claim 12, wherein:

said differential phase shift keyed (DPSK) type telecommunications signals are differential quadrature phase shift keyed (DQPSK) telecommunications signals, and said phase differences $\Delta(k_i)$ are selected from a set of phase differences $0, \pi/2, \pi$, and $3\pi/2$.

18. A method of demodulating differential phase shift keyed (DPSK) type telecommunications signals, comprising:

a) storing indications of quadrature components $X(q)$ and $Y(q)$ of N consecutive received symbols of the telecommunications signals, where q is an symbol index, and N is an integer equal to at least three;

b) processing said indications according to

$$VX_{i+1}(k_1, k_2, \dots, k_i) = VX_i(k_1, k_2, \dots, k_{i-1}) + UX_{i+1}(k_1, k_2, \dots, k_i),$$

$$VY_{i+1}(k_1, k_2, \dots, k_i) = VY_i(k_1, k_2, \dots, k_{i-1}) + UY_{i+1}(k_1, k_2, \dots, k_i),$$

where i is an iteration index with $i=1,2,\dots,N-1$, k_i is an index of a phase differences between symbols with $k_i = 1,2,\dots,M$, with M being the number of permissable phase transitions, and where $VX_{i+1}(k_1, k_2, \dots, k_i)$ and $VY_{i+1}(k_1, k_2, \dots, k_i)$ are quadrature components at the i -th iteration, such that $VX_1=X(q-N+1)$, $VY_1=Y(q-N+1)$ are quadrature components of the first received symbol in the sequence of said N symbols, and $UX_{i+1}(k_1, k_2, \dots, k_i)$ and $UY_{i+1}(k_1, k_2, \dots, k_i)$ are transforms of the received symbol at the i -th step according to

$$UX_{i+1}(k_1, k_2, \dots, k_i) = X(q-N+i+1)\cos[\Delta(k_1)+\dots+\Delta(k_i)] + Y(q-N+i+1)\sin[\Delta(k_1)+\dots+\Delta(k_i)]$$

$$UY_{i+1}(k_1, k_2, \dots, k_i) = Y(q-N+i+1)\cos[\Delta(k_1)+\dots+\Delta(k_i)] - X(q-N+i+1)\sin[\Delta(k_1)+\dots+\Delta(k_i)];$$

and

c) determining a current symbol based on a phase difference $\Delta(k_i)$ corresponding to a maximum length of vectors defined by a relationship utilizing $VX_{i+1}(k_1, k_2, \dots, k_i)$ and $VY_{i+1}(k_1, k_2, \dots, k_i)$.

19. A method according to claim 18, wherein:

said relationship is $[VX_{i+1}(k_1, k_2, \dots, k_i)]^2 + [VY_{i+1}(k_1, k_2, \dots, k_i)]^2$.

20. A method according to claim 18, wherein:

said storing comprises storing said indications in memory.

21. A method according to claim 18, wherein:

said storing comprises storing said memory in shift registers.

22. A method according to claim 18, wherein:

said processing comprises processing with a plurality of intersymbol processors, a first of said plurality of intersymbol processors generating two-symbol quadrature components VX_2 and VY_2 utilizing said quadrature components $X(q)$ and $Y(q)$ of a first two of said N consecutive received symbols, and a second of said intersymbol processors generating three-symbol quadrature components VX_3 and VY_3 utilizing said two-symbol quadrature components and a third of said N consecutive received symbols.

23. A method according to claim 22, wherein:

said processing with a plurality of intersymbol processors comprises processing with $N-1$ intersymbol processors.

24. A method according to claim 23, wherein

$N=3$.

25. A method according to claim 18, wherein:

said differential phase shift keyed (DPSK) type telecommunications signals are differential quadrature phase shift keyed (DQPSK) telecommunications signals, and said phase differences $\Delta(k_i)$ are selected from a set of phase differences $0, \pi/2, \pi$, and $3\pi/2$.

26. A method according to claim 25, wherein:

said processing comprises utilizing tables.

27. A method according to claim 25, wherein:

$N=4$.

28. A method of demodulating differential phase shift keyed (DPSK) type telecommunications signals, comprising:

- a) storing quadrature components $X(q)$ and $Y(q)$, $X(q-1)$ and $Y(q-1)$, $X(q-2)$ and $Y(q-2)$ of three consecutive symbols having indexes q , $(q-1)$ and $(q-2)$;
- b) transforming quadrature components $X(q-1), Y(q-1)$ and $X(q-2), Y(q-2)$ into a set of 2-symbol quadrature components VX_2 and VY_2 using each possible phase difference $\Delta(k_1)$, where $k_1=1, 2, \dots, M$;
- c) transforming quadrature components $X(q)$ and $Y(q)$ of a current symbol having index q into a set of transforms $UX_3(k_1, k_2)$ and $UY_3(k_1, k_2)$ for each possible combination of phase differences $\Delta(k_1)$ and $\Delta(k_2)$, where $k_1=1, 2, \dots, M$ and $k_2=1, 2, \dots, M$;
- d) obtaining sets of 3-symbol quadrature components $VX_3(k_1, k_2)$ and $VY_3(k_1, k_2)$ by combining results of said set of 2-symbol quadrature components VX_2 and VY_2 and said set of transforms $UX_3(k_1, k_2)$ and $UY_3(k_1, k_2)$;
- e) using said 3-symbol quadrature components $VX_3(k_1, k_2)$ and $VY_3(k_1, k_2)$, finding a vector having a maximum length of vectors $[VX_3(k_1, k_2), VY_3(k_1, k_2)]$; and
- f) making a decision relative to the current (q -th) symbol based on a phase difference of a set of differences $\Delta(k_2)$, where $k_2=1, 2, \dots, M$, corresponding to said vector having a maximum length.

29. A method according to claim 28, wherein:

said transforming quadrature components $X(q-1), Y(q-1)$ and $X(q-2), Y(q-2)$ into a set of 2-symbol quadrature components VX_2 and VY_2 is accomplished according to

$$VX_2(k_1) = X(q-2) + X(q-1)\cos[\Delta(k_1)] + Y(q-1)\sin[\Delta(k_1)],$$

$$VY_2(k_1) = Y(q-2) + Y(q-1)\cos[\Delta(k_1)] - X(q-1)\sin[\Delta(k_1)].$$

30. A method according to 28, wherein:

said transforming quadrature components $X(q)$ and $Y(q)$ of a current symbol having index q into a set of transforms $UX_3(k_1, k_2)$ and $UY_3(k_1, k_2)$ is accomplished according to

$$UX_3(k_1, k_2) = X(q)\cos[\Delta(k_1) + \Delta(k_2)] + Y(q)\sin[\Delta(k_1) + \Delta(k_2)] ,$$

$$UY_3(k_1, k_2) = Y(q)\cos[\Delta(k_1) + \Delta(k_2)] - X(q)\sin[\Delta(k_1) + \Delta(k_2)].$$

31. A method according to claim 28, wherein:

said combining results comprises adding according to

$$VX_3(k_1, k_2) = VX_2(k_1) + UX_3(k_1, k_2);$$

$$VY_3(k_1, k_2) = VY_2(k_1) + UY_3(k_1, k_2).$$

32. A method according to claim 28, wherein:

said finding a vector having a maximum length is found according to

$$\text{Max } \{ [VX_3(k_1, k_2)]^2 + [VY_3(k_1, k_2)]^2 \}.$$

33. A method according to claim 29, wherein:

said transforming quadrature components $X(q)$ and $Y(q)$ of a current symbol having index q into a set of transforms $UX_3(k_1, k_2)$ and $UY_3(k_1, k_2)$ is accomplished according to

$$UX_3(k_1, k_2) = X(q)\cos[\Delta(k_1) + \Delta(k_2)] + Y(q)\sin[\Delta(k_1) + \Delta(k_2)] ,$$

$$UY_3(k_1, k_2) = Y(q)\cos[\Delta(k_1) + \Delta(k_2)] - X(q)\sin[\Delta(k_1) + \Delta(k_2)] ,$$

said combining results comprises adding according to

$$VX_3(k_1, k_2) = VX_2(k_1) + UX_3(k_1, k_2),$$

$$VY_3(k_1, k_2) = VY_2(k_1) + UY_3(k_1, k_2), \text{ and}$$

said finding a vector having a maximum length is found according to

$$\text{Max } \{ [VX_3(k_1, k_2)]^2 + [VY_3(k_1, k_2)]^2 \}.$$

34. A method according to claim 28, wherein:

said transforming quadrature components $X(q-1), Y(q-1)$ and $X(q-2), Y(q-2)$ into a set of 2-symbol quadrature components comprises using a first intersymbol processor, and

said transforming quadrature components $X(q)$ and $Y(q)$ of a current symbol and said obtaining sets of 3-symbol quadrature components comprises using a second intersymbol processor.

35. A method according to claim 28, wherein:

said differential phase shift keyed (DPSK) type telecommunications signals are differential quadrature phase shift keyed (DQPSK) telecommunications signals, and said phase differences $\Delta(k_i)$ are selected from a set of phase differences $0, \pi/2, \pi$, and $3\pi/2$.

36. A method according to claim 35, wherein:

said transforming quadrature components $X(q-1), Y(q-1)$ and $X(q-2), Y(q-2)$ into a set of 2-symbol quadrature components, said transforming quadrature components $X(q)$ and $Y(q)$ of a current symbol having index q into a set of transforms $UX_3(k_1, k_2)$ and $UY_3(k_1, k_2)$, and said obtaining sets of 3-symbol quadrature components $VX_3(k_1, k_2)$ and $VY_3(k_1, k_2)$ comprises utilizing tables.

37. A method of demodulating differential phase shift keyed (DPSK) type telecommunications signals, comprising:

- a) storing quadrature components $X(q), Y(q), X(q-1), Y(q-1), \dots, X(q-N+1), Y(q-N+1)$ of N consecutive symbols having indexes $q, (q-1), \dots, (q-N+1)$;
- b) subjecting said quadrature components $X(q), Y(q); X(q-1), Y(q-1); \dots; X(q-N+1), Y(q-N+1)$ to a $(N-1)$ -step transformation, where an i -th iteration of said $(N-1)$ -step transformation, $i=1, 2, \dots, N-1$, includes

(1) calculating multi-dimensional transforms $UX_{i+1}(k_1, k_2, \dots, k_i)$ and $UY_{i+1}(k_1, k_2, \dots, k_i)$ of the current received components $X(q-N+i+1)$ and $Y(q-N+i+1)$ according to

$$UX_{i+1}(k_1, k_2, \dots, k_i) = X(q-N+i+1)\cos[\Delta(k_1)+\dots+\Delta(k_i)] + Y(q-N+i+1)\sin[\Delta(k_1)+\dots+\Delta(k_i)]$$

$$UY_{i+1}(k_1, k_2, \dots, k_i) = Y(q-N+i+1)\cos[\Delta(k_1)+\dots+\Delta(k_i)] - X(q-N+i+1)\sin[\Delta(k_1)+\dots+\Delta(k_i)], \text{ and}$$

(2) calculating multi-dimensional components $VX_{i+1}(k_1, k_2, \dots, k_i)$ and $VY_{i+1}(k_1, k_2, \dots, k_i)$ according to

$$VX_{i+1}(k_1, k_2, \dots, k_i) = VX_i(k_1, k_2, \dots, k_{i-1}) + UX_{i+1}(k_1, k_2, \dots, k_i),$$

$$VY_{i+1}(k_1, k_2, \dots, k_i) = VY_i(k_1, k_2, \dots, k_{i-1}) + UY_{i+1}(k_1, k_2, \dots, k_i),$$

where k_i is an index of a phase differences between symbols with $k_i = 1, 2, \dots, M$, with M being the number of permissible phase transitions; and

c) making a decision relative to a current q -th symbol using a phase difference from the set of differences $\Delta(k_{N-1})$, where $k_{N-1}=1, 2, \dots, M$, corresponding to a vector having a maximum length among vectors $[VX_N(k_1, k_2, \dots, k_{N-1}), VY_N(k_1, k_2, \dots, k_{N-1})]$.

38. A method according to claim 37, wherein:

said subjecting said quadrature components to a $(N-1)$ -step transformation comprises utilizing $N-1$ intersymbol processors.

39. A method according to claim 37, wherein:

said storing comprises storing in memory.

40. A method according to claim 37, wherein:

said storing comprises storing in shift registers.

41. A method according to claim 37, wherein:

said differential phase shift keyed (DPSK) type telecommunications signals are differential quadrature phase shift keyed (DQPSK) telecommunications signals, and said phase differences $\Delta(k_i)$ are selected from a set of phase differences $0, \pi/2, \pi$, and $3\pi/2$.

42. A method according to claim 41, wherein:

said subjecting said quadrature components to a $(N-1)$ -step transformation comprises utilizing processing comprises utilizing tables.